Investigation into the Link between Object Perception and Neural Activity in the Human Brain Using ECoG Data

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Abstract

One area under investigation in the field of neuroscience is the link between object perception and neural activity in visual cortical areas of the human brain. By investigating the electrical potentials from the ventral temporal cortical surface in humans, the Stanford University study selected for this paper sought to collect sufficient information for spontaneous and near-instantaneous identification of a subject's perceptual state. The brain signal data collection technique used by the researchers was electrocorticography (ECoG), using ECoG arrays placed on the subtemporal cortical surface of seven epilepsy patients. ECoG is an invasive electrogram method, requiring access to the surface of the brain, which can be applied to measure brain signals in response to specific stimuli. Using publicly available human ECoG recording data previously collected and made publicly available, this paper investigates visual object processing in the human brain. The data are taken from a study where seven epilepsy patients were shown house and face images in quick succession. We use those data and filter, process, and plot selected data to investigate the correct identification of the stimuli. We discovered that the incorrect stimuli matches are driven by variance in the human brain activity corresponding to the same set of stimuli. Better understanding of the visual processing capabilities of the human brain

could lead to developments in machine learning, as well as generate recommendations for future data collection in human visual object processing.

1. Introduction

Epilepsy is the fourth most common neurological disorder in the United States [6]. It is associated with unpredictable seizures of variable severity and can lead to other health problems. A person of any age can suffer from epilepsy [10].

Epilepsy neuronal activity is most commonly captured by electro-encephalography (EEG) since it is non-invasive and relatively inexpensive [14] but can also be recorded by electro-corticography (ECoG), which is a related modality. Using either method, epilepsy seizure activity appears as rapid spiking waves.

ECoG is an invasive method to record brain signals. The electrodes are placed directly on the surface of the cerebral cortex, which allows ECoG to identify faster and smaller nuclei of brain activity. This can be accomplished at higher spatial and temporal resolutions than EEG [1]. EEG is a traditional and widely-used method for recording brain signals, while ECoG has been gaining popularity in clinical settings for investigating cortical phenomena [5].

One area of neuroscience that has been researched throughout the years is the link between object perception and neural activity in visual cortical areas of the human brain. One subset of this area is figure-ground segregation. Previous studies have suggested that figure-ground segregation is dependent on feedback loops between lower and higher areas of the visual cortex [3,7,11,12]. Figure-ground separation is one paradigm that can be considered useful in the investigation of the link between object perception and neural activity in visual cortical areas. One study investigated the figure-ground separation neural activity in mice [13]. There have been additional studies into this neural link in visual cortical areas that reveal feedback loops as playing a key role in visual object perception [4].

2. Materials and Methods

2.1. Experimental Protocols

Researchers at Stanford University implanted electrodes on the brains of seven epileptic patients and then presented them with a basic image viewing task. The task involved differentiating between faces and houses in order to ascertain the spontaneous and near-instantaneous identification of a subject's perceptual state [8,9].

The researchers sought to gather sufficient data to develop methods to predict the occurrence, timing and type of visual stimulus. They evaluated both broadband changes in brain signals and event-related potentials (ERPs) [8,9].

2.2. Data Collection

Data Set: Miller, Kai J and Ojemann, Jeffrey G. (2015). Data and analyses for "Spontaneous Decoding of the Timing and Content of Human Object Perception from Cortical Surface Recordings Reveals Complementary Information in the Event-Related Potential and Broadband Spectral Change". Stanford Digital Repository. Available at: http://purl.stanford.edu/xd109qh3109 [8]

Ethics Statement: All patients participated in a purely voluntary manner, after providing informed written consent, under experimental protocols approved by the Institutional Review Board of the University of Washington (#12193). All patient data was anonymized according to IRB protocol, in accordance with HIPAA mandate. These data originally appeared in the manuscript "Spontaneous Decoding of the Timing and Content of Human Object Perception from Cortical Surface Recordings Reveals Complementary Information in the Event-Related Potential and Broadband Spectral Change" published in PLoS Computational Biology in 2015 [8].

The ECoG arrays were placed on the subtemporal cortical surface in order to record electrical potential data from the ventral temporal cortical surface [8,9].

The face-house discrimination task involved the presentation of 50 house pictures and 50 face pictures that were presented for 400ms per picture in each of the three experimental runs, for a total exposure to 300 visual stimuli. The patients were asked to verbally report a simple stimulus, such as a house, in order to ensure the patient's concentration on the task runs. The images utilized were grayscale pictures of faces and houses (luminance- and contrast-matched) [8,9].

2.3. Data Processing

We used MATLAB (Mathworks, Natick, MA) for data processing. We processed the researchers' data, which was available in the MATLAB *.mat* file format. We reviewed the analyses from the researchers' manuscript, available in the MATLAB *.m* file format, and then produced our own scripts.

A 12th order lowpass digital Butterworth filter with cutoff frequency of 10% of the sampling rate was applied to all the patients' data in order to select a few sets of patient data that had the least random high amplitude peaks or troughs (i.e., greater than eight standard deviations).

3. Results

3.1. Analysis

We investigated the first task runs of the Patients CA (age 31, male), JA (age 37, male) and WC (age 32, male).

From the processed ECoG data shown in the figures, some patterns can be observed. During the sessions, all patients showed brain activity peaks during pre-post task runs, basic face and house stimulus discrimination task, and interstimulus intervals. Great variation in patterns of brain activity response to visual stimuli was recorded for both face and house images. High amplitudes in brain wave activity were observed in both periods of visual stimulus and interstimulus intervals.

3.2. Limitations

This author did not collect the experimental data herself, so she is not knowledgeable of all the proceedings during the data collection sessions. In addition, patient privacy laws do not allow her to have more data about the epileptic patients other than their ages and genders.

ECoG can collect brain activity data at higher spatial and temporal resolutions than EEG [1]. However, that results in limited brain areas to investigate and greater variance in data due to the high data collection rates (e.g., 10,000 Hz).

4. Discussion

Overall plots of the testing of the patients can be viewed in Figure 1. There were three task runs, each with interstimulus interval data collected. The same set of three task runs were presented to each of the Patients CA, JA and WC.

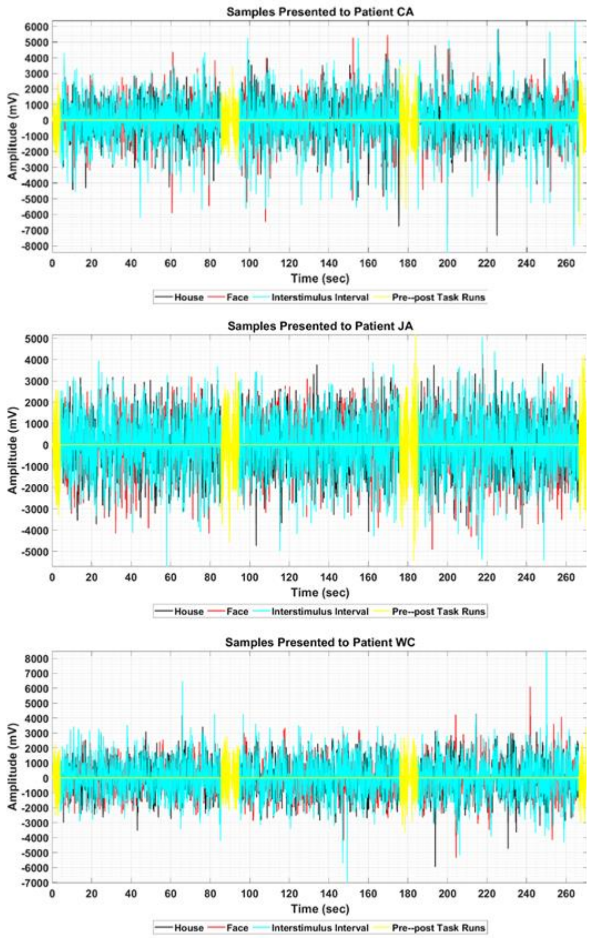

Figure 1. Each patient was presented with three task runs.

Figure 2 takes a closer look at the order of the different images presented in the same ten-second interval, between 5 to 10 seconds after the start of the task run, for those three patients. The first two electrodes for each patient were selected for the following figure. Both the amplitudes and shapes of the brain activity varied for each patient.

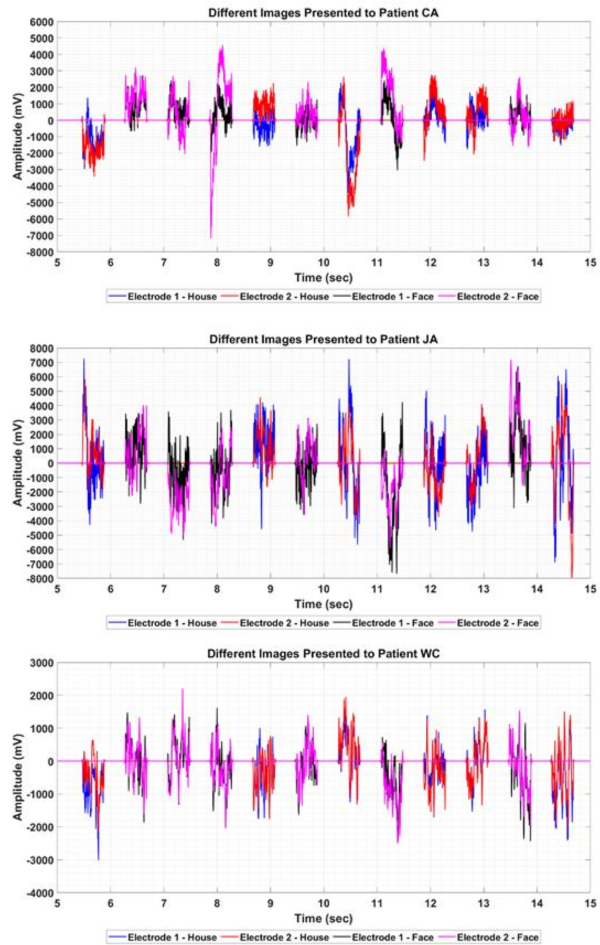

Figure 2. Face and house images presented to each patient between 5 seconds and 15 seconds into the first task run. The different colors indicate the different electrodes – red and blue for the house image, pink and black for the face image (labelled in the legends as well).

The interstimulus brain activity for those same images presented in the same ten-second time period, between 5 to 10 seconds after the start of the task run, for each of the three patients can be viewed in Figure 3. The interstimulus interval data in blue shows brain activity when patients were not being presented with visual stimuli; the brain waves were of relatively high amplitude.

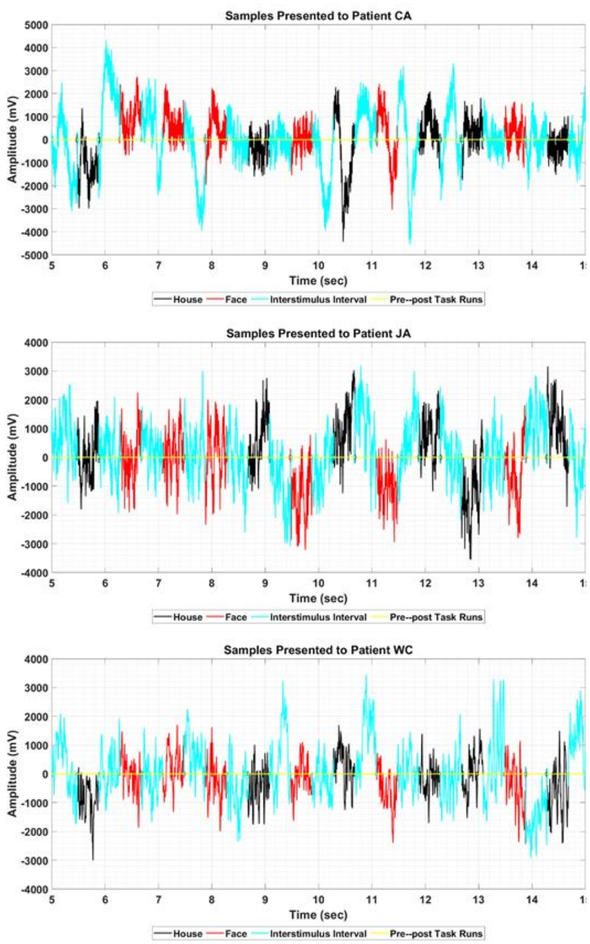

Figure 3. All the various activity periods for 5 seconds and 15 seconds into the first task run.

The responses of five different electrodes during the presentation of the first house image for each of the three patients is shown in Figure 4. Both the amplitudes and shapes of the brain activity varied for each patient.

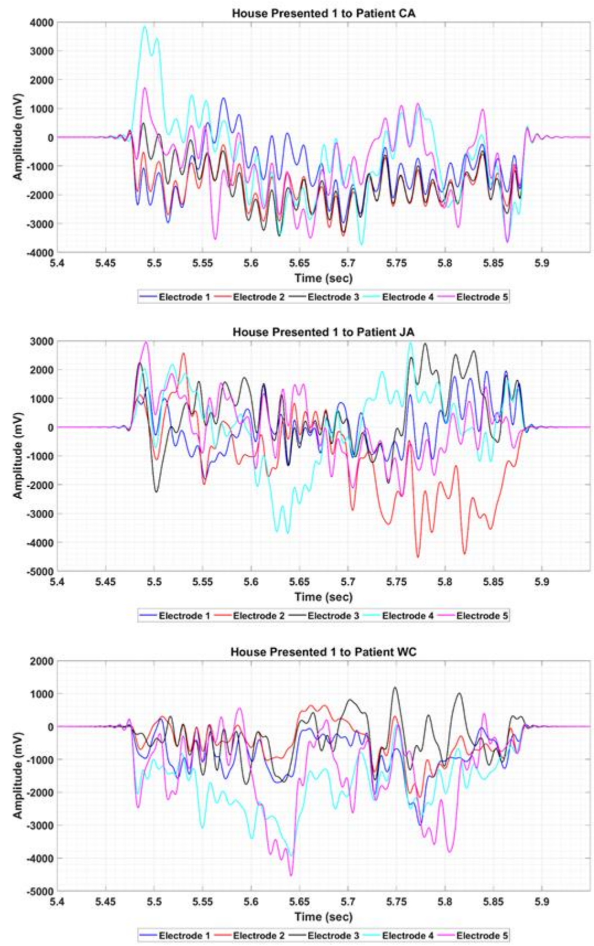

Figure 4. Each patient's brain activity when presented with the first house image. All five selected electrodes are plotted in a different color, as indicated by the legends.

In addition, the amplitude and shape of each patient's brain activity response pattern varied greatly for the presentation of the first two house images (Figure 5).

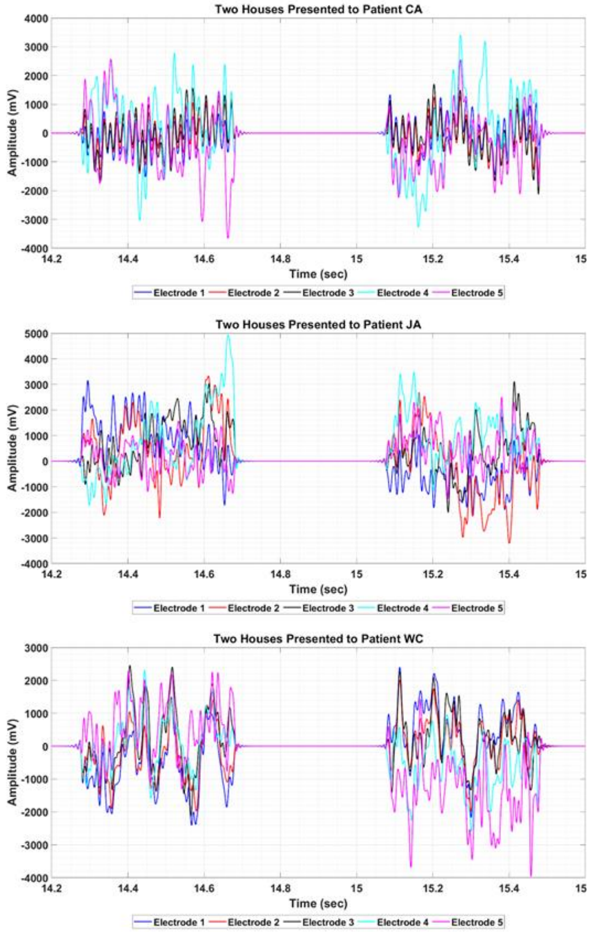

Figure 5. Each patient's brain activity when presented with two houses within one second of each other.

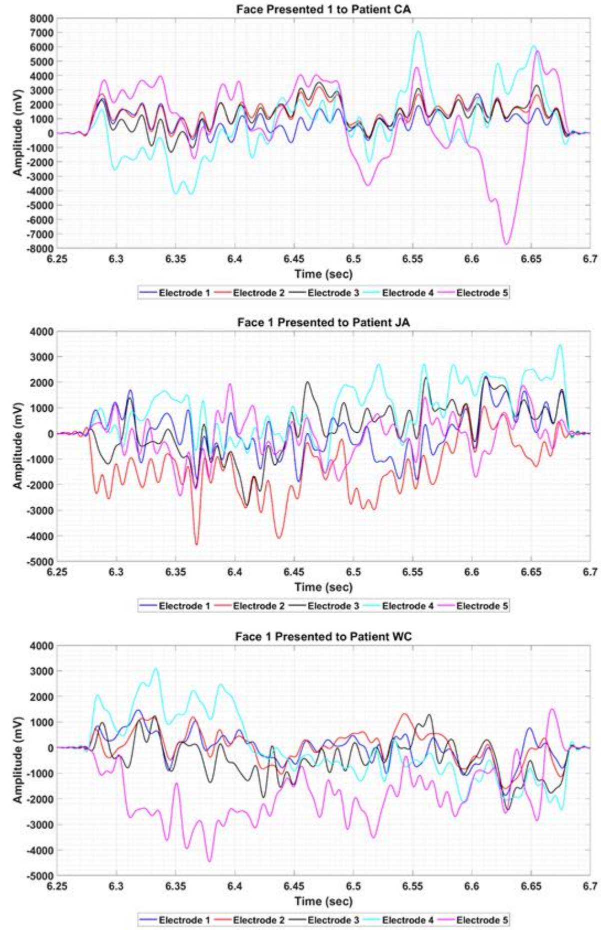

Figure 6. Each patient's brain activity when presented with the first face image.

The responses of five different electrodes during the presentation of the first face image for each of the three patients is shown in Figure 6. Similar to Figure 4, both the amplitudes and the shapes of the brain activity response varied for each patient.

Similar to Figure 5, each patient's brain activity response pattern varied greatly for the presentation of the first two face images (Figure 7). Note the great change in amplitude for Patient CA.

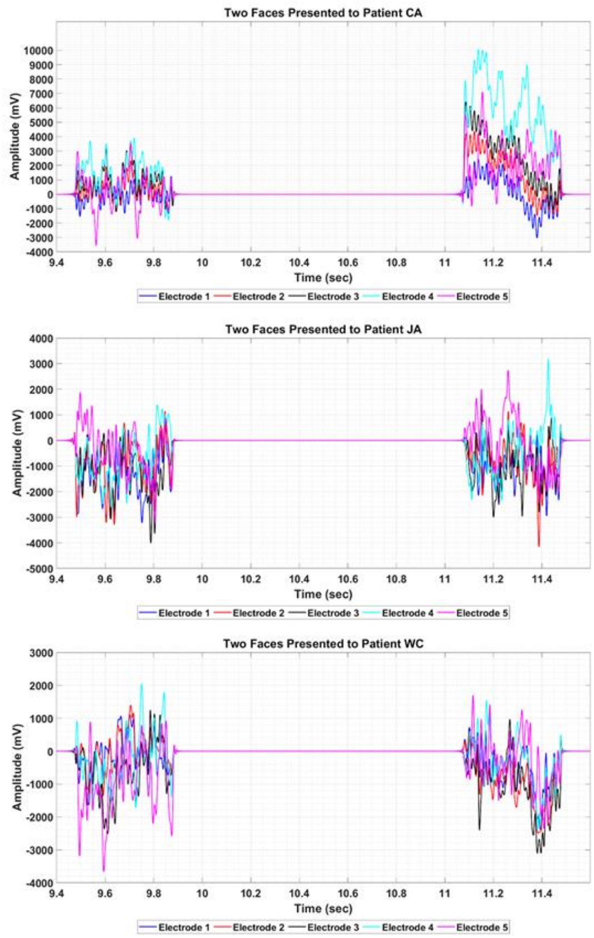

Figure 7. Each patient's brain activity when presented with two face images within 2 seconds of each other.

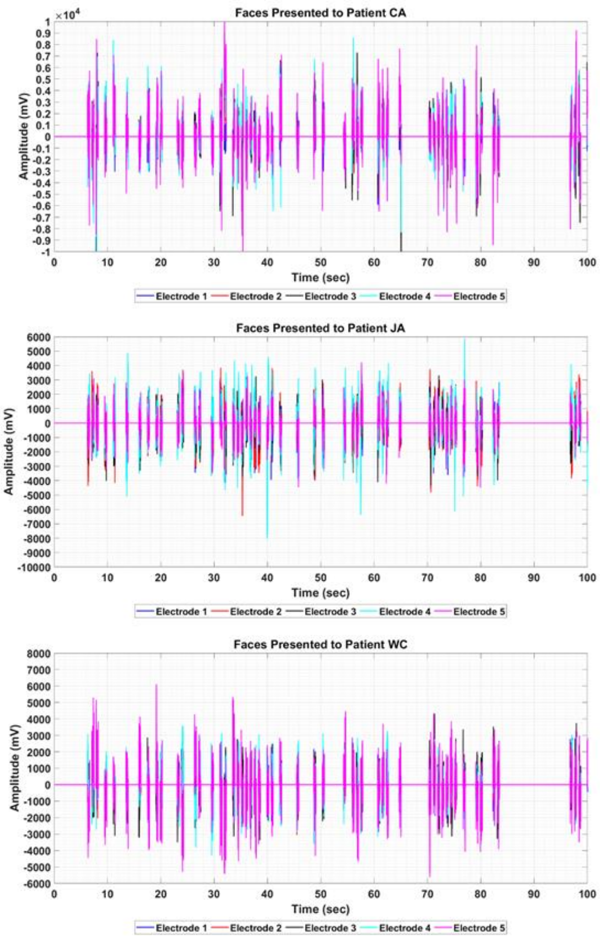

Figure 8. An overview of each patient's brain activity when presented with the face images within the first 100 seconds of the task runs.

Figure 8 displays and overview of each patient's brain activity when presented with the face images within the first 100 seconds of the task runs, which highlights the differing amplitudes of the brain activity response to the face stimuli. Again, five electrodes were selected to be plotted.

Figure 9 displays and overview of each patient's brain activity when presented with the face images within the first 100 seconds of the task runs, which highlights the differing amplitudes of the brain activity response to the face stimuli. Again, five electrodes were selected to be plotted.

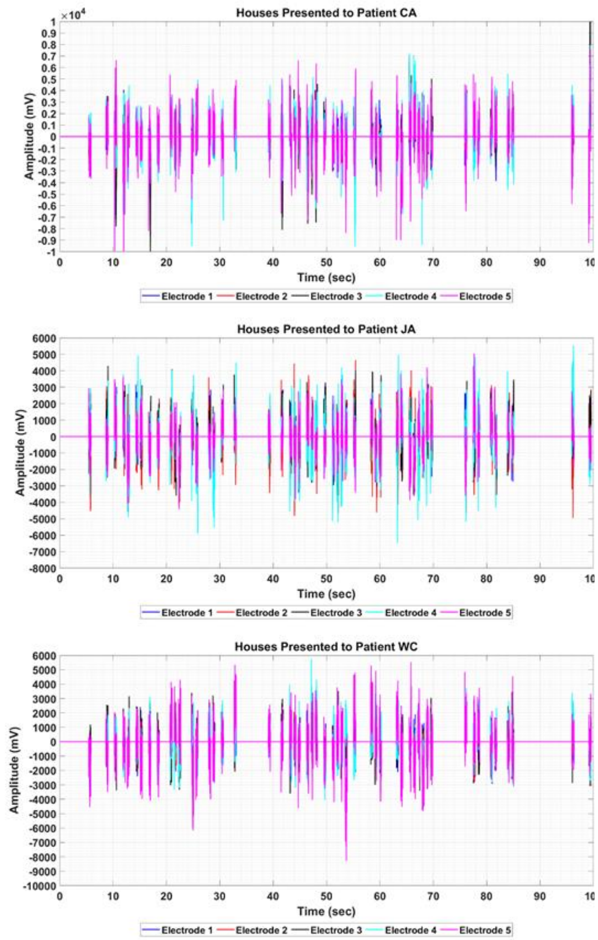

Figure 9. An overview of each patient's brain activity when presented with the house images within the first 100 seconds of the task runs.

5. Conclusion

EEG is a commonly used and well-established method of collecting brain signal data. On the other hand, ECoG has been growing in popularity in clinical settings for investigating cortical phenomena due to its higher spatial and temporal resolution. However, ECoG is much more invasive than EEG and costs significantly more.

One aspect of cortical phenomena that ECoG can investigate is the link between object perception and neural activity in visual cortical areas of the human brain. One subset of this area is figure-ground segregation, for both animal and human subjects.

This paper is a review of a previously published basic image viewing task that was presented to seven epilepsy patients in order to assess the object perception in their visual cortical areas using ECoG. We investigated the data sets belonging to Patients CA, JA and WC and we concluded that their data showed a great variety in different brain activity, both shape and amplitude, for different patients seeing the same set of images. When comparing brain activity to only house images or only face images, there could be significant differences in amplitude.

In addition, brain recovery data was also recorded during interstimulus intervals. That interstimulus interval data showed the most variance in the data. In general, the amplitudes of the interstimulus interval data were much greater than the amplitudes of the brain waves that correspond to the responses to the face and house images. The greater amplitude is in accordance with the differing amplitudes of alpha, beta, gamma, delta and theta brain waves that correspond to the categories of brain activity [16]; higher amplitude signifies lower level of brain activity during interstimulus intervals.

The Stanford researchers investigated whether or not the event-related broadband (ERBB) and event-related potential (ERP) provided enough useful information to determine the stimulus presented. Our plots in the previous section displayed a great variety of reactions to the same sets of stimuli, while the Stanford researchers concluded that stimuli could be categorized and identified reliably 96% of the time by using either ERBB or ERP. The 4% of stimuli not accurately matched by their model could be attributed to the variance in the ECoG data observed by us [8,9].

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References

1. Akinin, A. Paul, J. Wang, A. Buccino, and G. Cauwenberghs, "Biopotential Measurements and Electrodes," in *Neural Engineering*, B. He, Ed. Cham: Springer International Publishing, 2020, pp. 65–96. doi: 10.1007/978-3-030-43395-6_2.
2. R. G. Andrzejak, K. Lehnertz, F. Mormann, C. Rieke, P. David, and C. E. Elger, "Indications of nonlinear deterministic and finite-dimensional structures in time series of brain electrical activity: Dependence on recording region and brain state," *Phys. Rev. E*, vol. 64, no. 6, p. 061907, Nov. 2001, doi: 10.1103/PhysRevE.64.061907.
3. A. Angelucci, M. Bijanzadeh, L. Nurminen, F. Federer, S. Merlin, and P. C. Bressloff, "Circuits and Mechanisms for Surround Modulation in Visual Cortex," *Annual Review of Neuroscience*, vol. 40, no. 1, pp. 425–451, 2017, doi: 10.1146/annurev-neuro-072116-031418.
4. J. L. Breedlove, G. St-Yves, C. A. Olman, and T. Naselaris, "Generative Feedback Explains Distinct Brain Activity Codes for Seen and Mental Images," *Current Biology*, vol. 30, no.

12, pp. 2211-2224.e6, Jun. 2020, doi: 10.1016/j.cub.2020.04.014.

5. G. Buzsáki, C. A. Anastassiou, and C. Koch, “The origin of extracellular fields and currents — EEG, ECoG, LFP and spikes,” *Nat Rev Neurosci*, vol. 13, no. 6, pp. 407–420, Jun. 2012, doi: 10.1038/nrn3241.
6. D. Hirtz, D. J. Thurman, K. Gwinn-Hardy, M. Mohamed, A. R. Chaudhuri, and R. Zalutsky, “How common are the ‘common’ neurologic disorders?,” *Neurology*, vol. 68, no. 5, pp. 326–337, Jan. 2007, doi: 10.1212/01.wnl.0000252807.38124.a3
7. V. A. Lamme, “The neurophysiology of figure-ground segregation in primary visual cortex,” *J. Neurosci.*, vol. 15, no. 2, pp. 1605–1615, Feb. 1995, doi: 10.1523/JNEUROSCI.15-02-01605.1995.
8. K. J. Miller and J. G. Ojemann, “Data and analyses for ‘Spontaneous Decoding of the Timing and Content of Human Object Perception from Cortical Surface Recordings Reveals Complementary Information in the Event-Related Potential and Broadband Spectral Change,’” *Stanford Research Data*, 2015, Accessed: Mar. 20, 2022. [Online]. Available: https://purl.stanford.edu/xd109qh3109
9. K. J. Miller, G. Schalk, D. Hermes, J. G. Ojemann, and R. P. N. Rao, “Spontaneous Decoding of the Timing and Content of Human Object Perception from Cortical Surface Recordings Reveals Complementary Information in the Event-Related Potential and Broadband Spectral Change,” *PLOS Computational Biology*, vol. 12, no. 1, p. e1004660, Jan. 2016, doi: 10.1371/journal.pcbi.1004660.
10. P. Obsorne Shafer and J. I. Sirven, “Epilepsy Statistics,” *Epilepsy Foundation*, Oct. 2013. https://www.epilepsy.com/learn/about-epilepsy-basics/epilepsy-statistics (accessed Apr. 17, 2022).
11. P. R. Roelfsema, “CORTICAL ALGORITHMS FOR PERCEPTUAL GROUPING | Annual Review of Neuroscience,” *Annual Review of Neuroscience*, vol. 29, pp. 203–227, Jul. 2006, doi: https://doi.org/10.1146/annurev.neuro.29.051605.112939.
12. P. R. Roelfsema, V. A. F. Lamme, H. Spekreijse, and H. Bosch, “Figure—Ground Segregation in a Recurrent Network Architecture,” *Journal of*

Cognitive Neuroscience, vol. 14, no. 4, pp. 525–537, May 2002, doi: 10.1162/08989290260045756.

13. U. H. Schnabel, C. Bossens, J. A. M. Lorteije, M. W. Self, H. Op de Beeck, and P. R. Roelfsema, "Figure-ground perception in the awake mouse and neuronal activity elicited by figure-ground stimuli in primary visual cortex," *Sci Rep*, vol. 8, no. 1, Art. no. 1, Dec. 2018, doi: 10.1038/s41598-018-36087-8.
14. D. L. Sherman and N. V. Thakor, "EEG Signal Processing: Theory and Applications," in *Neural Engineering*, B. He, Ed. Cham: Springer International Publishing, 2020, pp. 97–129. doi: 10.1007/978-3-030-43395-6_3.
15. "Electroencephalogram (EEG)." https://www.hopkinsmedicine.org/health/treatment-tests-and-therapies/electroencephalogram-eeg (accessed Apr. 17, 2022).
16. "What are Brainwaves? - Improve Brain Health with Neurofeedback," Sinha Clinic, 2022. https://www.sinhaclinic.com/what-are-brainwaves/ (accessed May 05, 2022).